Geotechnical Properties of Soft Clay Soil Stabilized by Reed Ashes

Hussein H. Karim[1], Zeena W. Samueel[2], and Salsabeel F. Ahmed[3]

Abstract*—Problematic soil, particularly soft clay, is wide spread in southern Iraq which is characterized by its low bearing capacity and strength besides its low California bearing ratio (CBR). The aim of this research is to investigate the suitability of some local natural material to be used as a stabilizer for soft soil such as reed ash (RA), which is available in Iraq with low cost. The immediate effect of the addition of such organic material ashes (biomass ashes) to the soil much like Portland cement is to cause flocculation and agglomeration of the clay particles. This study is carried out on soft soil brought from Maysan Governorate, southern Iraq. Different percentages of reed ash (RA) in incremental order of 3% up to 12% by dry weight of soil were added to natural soil sample. Physical and mechanical properties that have been studied before and after addition are specific gravity, consistency limit, unconfined compressive strength, compaction, California bearing ratio (CBR), consolidation, in addition to scanning electron microscope (SEM) and mineralogical analysis by X-ray diffraction (XRD). Testing results show that RA improved the consistency, strength, and deformation characteristics. It was found that the plasticity index of the natural soil has been decreased by about 22% with the addition of 12% RA. Treatment with RA showed a general reduction in the maximum dry unit weight with increase in the RA content to minimum values at 12% RA content. The optimum moisture content generally increased with increase in the RA content. There was colossal increase in the unconfined compressive strength value by about 86% and in the CBR value by about 227% with increase in RA content to 12%. A reduction in the compressibility index C_c from 0.196 to 0.073 was observed with increasing RA up to 12%. The angle of internal friction for soil-RA mix increased from 4° to 19° with 12% RA addition. Thus, it can be concluded that reed ash was an effective stabilizer for improving the geotechnical properties of soft soil samples and this will encourage the use of such matter as stabilizer in road building and obtaining a cheaper and effective replacement for the conventional soil stabilizers.

***Index* Terms— Soil Stabilization, Soft Clay, Reed Ash**

Manuscript received July 16, 2015; accepted August 23, 2015.

[1] Professor, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq. (corresponding author: e-mail: husn_irq@yahoo.com).

[2] Lecturer (Ph. D), Building and Construction Engineering Department, University of Technology, Baghdad, Iraq. (e-mail: zinawaleed2004@yahoo.com).

[3] M.Sc. in Geotechnical Engineering. (e-mail: sall.f.mashhadany@gmail.com).

I. Introduction

SOFT clay soils are recent alluvial deposits presumably formed through the most recent 10,000 years described by their featureless and flat ground surface. “References [1] and [2] identified such clays by their low undrained shear strength (C_u< 40 kPa) and high compressibility (C_c between 0.19 to 0.44)”. These soils are found at high natural moisture content (typically ranging from 40-60%) with plasticity index ranging from 45-65% [3]. Soils with such characteristics create serious problems to geotechnical engineering associated with stability and settlements problems [4]. A soft sub grade in construction of roadways is one of the most frequent problems for highway construction in many parts of the world [5].

This research focuses on studying the feasibility of improving geotechnical properties of soft clay soil with chemical admixtures obtained from the burning of reeds. As a matter of fact, reeds ash has never been used before as useful materials in Iraq. So, an attempt has been made to manufacture and examine this organic material ash for the first time in Iraq. The effort was made for several reasons: first to utilize a natural resource self-renewable, reed, which grown over a wide range of mid and southern parts of Iraq. Second, this material, reed, has been used in this product were very cheap, very popular and easily available.

II. MATERIALS USED

Soil

Soil samples used in this study were obtained from a location in Maymouna site (Latitude 31°54′ N and Longitude 47° 2′ E) about 393 km south of Baghdad near Al-Amarah City in Maysan Governorate, southern Iraq. This soil is collected by disturbed sampling from borrow pits at a depth of 1.5 m. The properties of the soft soil used in this investigation are given in Table 1. According to the USCS classification system [6], the soil is classified as CL soil. The plasticity chart showing the location of the soil is shown in Fig. 1.

Table 1. Physical and chemical properties of natural soil used.

Index Property	Index Value
Initial water content (WC) %	42
Depth (m)	1.5
Liquid Limit (L.L) (%)	45
Plastic Limit (P.L) (%)	25
Linear Shrinkage (SL) (%)	11
Plasticity Index (P.I) (%)	20
Activity (At)	0.50
Specific Gravity (Gs)	2.72
Gravel (larger than 2mm) (G) %	0
Sand (0.06 to 2mm) % (S)	0.5
Silt (0.005 to 0.06) (M)%	37.5
Clay (less than 0.005mm) (C)%	62
Classification (USCS)	CL
Organic Material (O.M) (%)	0.925
Calcium Oxide (CaO) (%)	14.616
SO_3 Content (%)	1.108
Total Dissolved Salt (TDS) (%)	4.91
pH Value (%)	8.16

Note: All tests were performed according to the ASTM (2002).

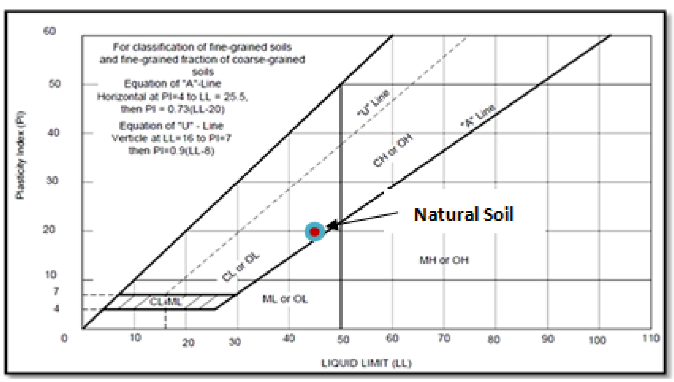


Fig. 1. Plasticity chart for the natural soil.

Organic Material Ash

The main ground improvement admixture used in this work was reed plants, which have been collected from Al-Amarah marshland area. At the beginning, the plants are spread on the ground and air dried to facilitate their burning.

Then, reed plants are burnt to be ash and then sieved through a sieve of 75µm to remove any tarnishes and get very fine reed ashes (RA). Then the sieved ashes were put in oven at 500^{o}C for two hours. Physical properties and chemical composition of this ash are given in Table 2.

Water

Ordinary drinking water was used in the experimental work.

Table 2. Physical properties and chemical composition of reed ash.

Description	Abbreviation	Value (Index)
Specific gravity	G.S	2.44
Silica (%)	SiO_2	65.2
Iron (%)	Fe_2O_3	2.6
Alumina (%)	Al_2O_3	12.3
Calcium (%)	Cao	6.4
Magnesium (%)	MgO	N.R
Sodium (%)	Na_2O	N.R
Potassium (%)	K_2O^{**}	2.5
Sulfur trioxide (%)	SO_3^{***}	1.52
Phosphorus (%)	P_2O_5	0.03
Chloride (%)	Cl	N.R
Titanium (%)	TiO_2	0.19
Manganese (%)	MnO	0.08
Moisture Content (%)	w	0
Loss on Ignition (%)	L.O.I	1.47

*Chemical composition values are calculated using EDX-7000 instrument.
**K_2O value is calculated using XRD-6000 instrument.
***SO_3 value is calculated using MXF-2400 instrument.

III. SAMPLING AND PREPARATION OF SOIL MIXTURES

Disturbed soil samples were used in this work. These samples were packed in nylon bags and they were transported to the Soil Mechanics Laboratory of the University of Technology. First, the soil is oven dried and then pulverized. The prepared samples are then mixed with the predetermined amount of stabilizer (RA), while the dosage rates can be determined in various ways. In this study, the best approach to characterize the measurements rate is taking into account the dry weight of soil to be dealt with. Accordingly, the amount of stabilizer to be used was found from the following formula:

$$\text{Amount of stabilizer} = \frac{(\text{ps} * \text{Wtot})}{(1+w)} \tag{1}$$

where:
ps = Percent by dry weight of stabilizer to be used,
Wtot = Wet weight of soil prior to addition of stabilizer, and
w = Moisture content of soil prior to addition of stabilizer, expressed as a decimal.

The selected percents of ash are (3, 6, 9 and 12%) of the dry weight of the untreated soil. The soil-additive mixtures were prepared by thoroughly mixing of dry quantities of soil and ash in a mixing tray to obtain a uniform color for a minimum of 5 minutes, and the required amount of distilled water was added to the dry mixtures. After that, the soil –ash mixture is mixed carefully until a homogeneous color was obtained.

IV. EXPERIMENTAL TESTS

Several tests are made to investigate the soil behavior after adding the RA. These tests are as presented in Table 3. All samples for UCS, CBR and compressibility tests were at the optimum moisture content (OMC) and maximum dry unit weight (MDD) values of the natural soil.

Table 3. Tests with their standards.

1. Specific Gravity [7].	2. Atterberg's Limits [8].
3. Modified compaction [9].	4. q_u (UCS) [10].
5. Unsoaked CBR & Soaked CBR [11].	6. Compressibility [12].
7. SEM (Scanning Electron Microscope).	8. XRD (X-Ray Powder Diffraction, (XRD).

V. TEST RESULTS AND DISCUSSION

The specific gravity of the treated soil decreased with increasing of reed ash (RA) content due to the its low values of the specific gravity (2.44) compared to that of the soil (2.72). The effect of RA on specific gravity of the soil is presented in Fig. 2. There was an increase in liquid limit and plastic limit, and a decrease in the plasticity index with increasing in RA content. The addition of RA at a maximum value of 12% result in an increase in liquid limit from 45 to 50.5%, plastic limit increased from 25 to 34.8%. Hence, plasticity index decreased from 20 to 15.7%. The reduction in the plasticity is attributed to the transformation in soil nature (granular nature after flocculation and agglomeration) and the resulted soil is as crumbly as silt soil.

The optimum moisture content (OMC) and the maximum dry unit weight (MDD) of the untreated natural soil were 17% and 18.62 kN/m^3 respectively. The addition of RA led to increase in OMC values and a reduction in the maximum dry unit weight values with the increasing in RA content from 0 to 12% as shown in Fig. 3. The effect of RA on unconfined compressive strength of the soil is presented in Fig. 4. When the RA content was increased from 0 to 12%, the unconfined compressive strength increased from 164 to 304.9 kPa. The chemical reactions that occur when RA is mixed with clay include pozzolanic reactions. These result in agglomeration in large size particles. CBR values increased from 4.9 to 16%, in RA stabilized samples with the addition of RA. This increase is due to pozzolanic reactions (the silica, SiO_2) from RA interacts with the Ca^{++} from the soil to form cementitious components (CSH), within the ash-soil mixture and resulting in strength gain over time. The effect of RA on unsoaked and soaked CBR of the soil is presented in Figs. 5 and 6. The addition of RA improved the compressibility of soft clay soil by reducing the compressibility index C_c from 0.196 to 0.073. And the reloading index C_r decreased from 0.0394 to 0.005. The effect of the RA addition on soil compressibility is presented in Fig. 7. The micrograph of the natural soil (Fig. 8) showed the sheet-like structure and flaky arrangement of the clay particles which is a closed fabric. While, Fig. 9a and b illustrates the micrographs of the treated soil and stabilized with 12% reed ash. Both micrographs of the treated soils with RA show crumbs of floccules with a porous nature and cementitious compounds (calcium silicate hydrate) coating the clay particles. Additionally, the reaction of reed ash with clay led to the formation of aggregates of various sizes and rod-like crystals (as a result of pozzolanic reaction). Mineralogical compositions (from XRD analysis) of the natural soil and reed ash (RA) are illustrated in Table 4. XRD patterns for natural soil and RA are shown in Figs. 10 and 11 while Fig. 12 illustrates the treated soil with 12% RA. XRD scan for RA showed a long amorphous hump from 20° to 34° (2θ). This hump pattern is most likely entirely a silica gel. From Fig. 12, one can notice a considerable increasing in calcite ($CaCO_3$) and CSH. There was a considerable increasing in quartz (SiO_2), anhydrite ($CaSO_4$), feldspar, halite ($NaCl$) and dolomite ($Ca(MgCO_3)_2$) content. The increase contents of feldspar and dolomite made the CBR and q_u of treated soil to gain up. The increasing of quartz (SiO_2) crystals content led to increase in sand-sized particles as well as increasing the pore voids size. Hence, reduction in plasticity index and swelling potential and increasing the CBR and q_u values of the stabilized soils are observed.

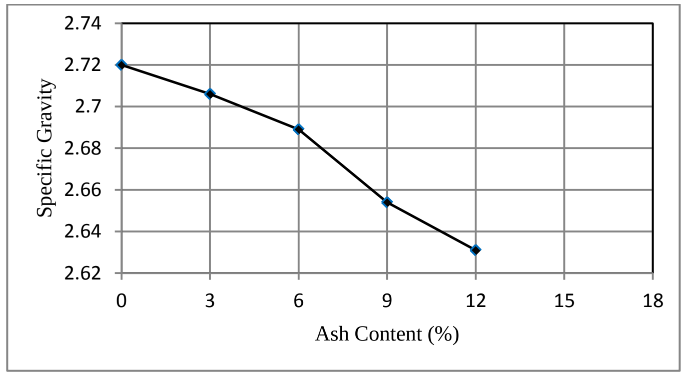


Fig. 2. Specific gravity for treated soil with RA content.

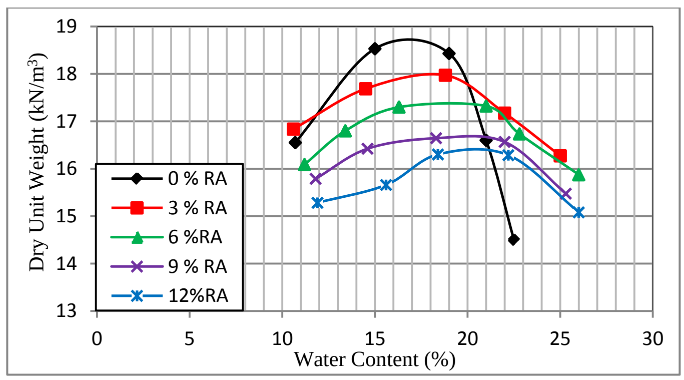


Fig. 3. Dry unit weight – water content curve for soil–RA mix.

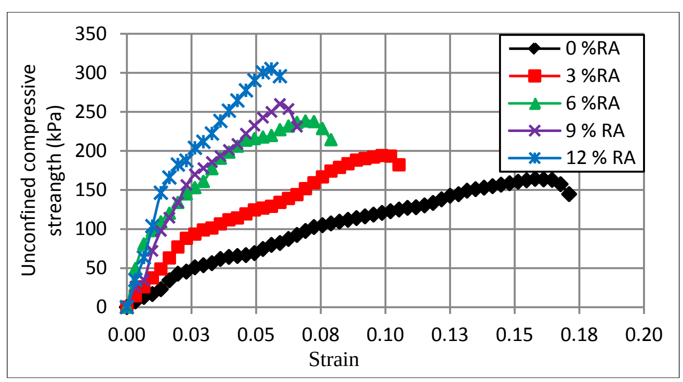


Fig. 4. Stress-Strain relationship from unconfined compression test for treated soil with RA.

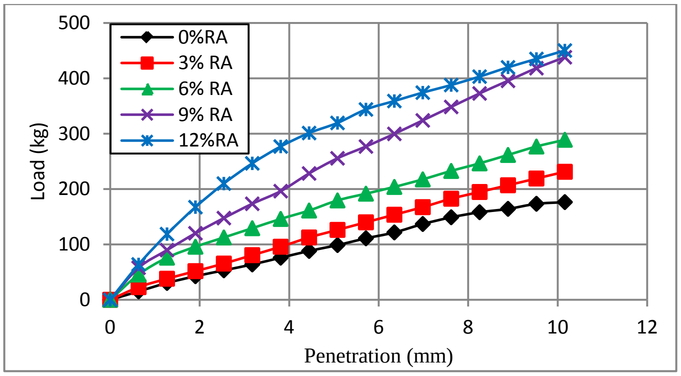


Fig. 5. Load-penetration relationship for unsoaked stabilized soil with RA.

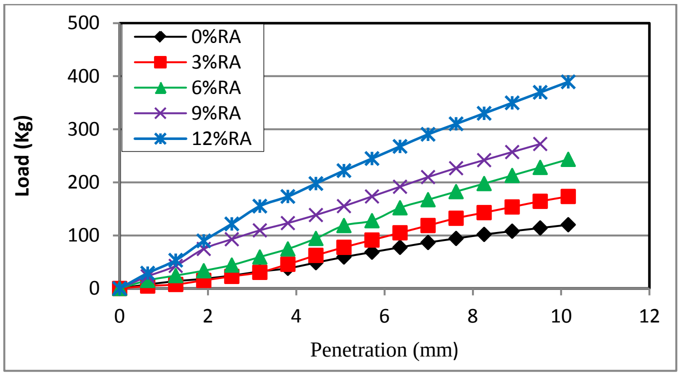


Fig. 6. Stress-penetration relationship for 4-days soaked stabilized soil with RA.

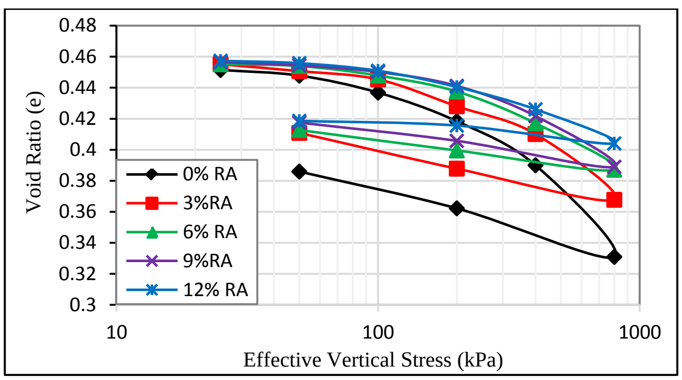


Fig. 7. Void ratio versus effective stress curves from the consolidation test on soil stabilized with different RA percents.

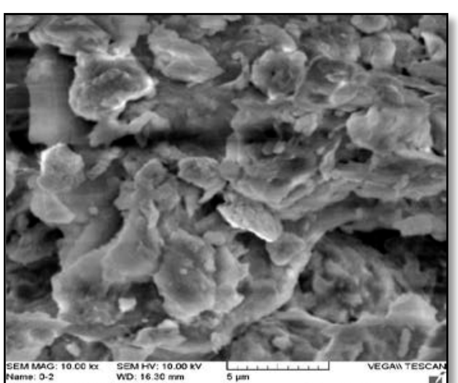


Fig. 8. SEM micrograph of natural soil.

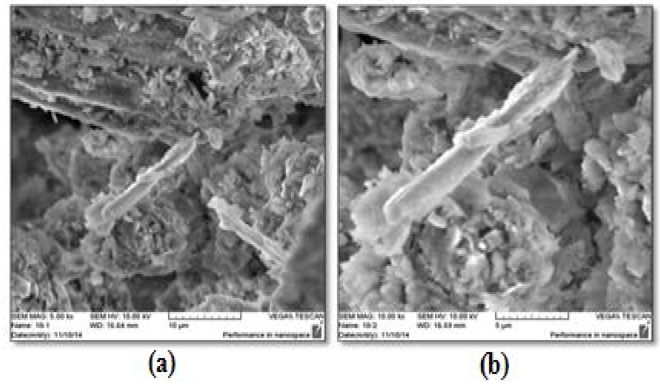


Fig. 9. SEM micrographs of (a) treated soil with 12% RA (b) magnified micrograph for the same specimen.

Table 4. Mineralogical composition (from XRD analysis) of the natural soil and reed ash (RA).

Material type	**Arrangement of the minerals according to the majority (from primary to secondary components)**
Natural Soil	Calcite ($CaCO_3$), Quartz (SiO_2), Muscovite, Halloysite, Dolomite (Ca ($MgCO_3$)$_2$), Illite, Feldspar, Montmorillonite and Kaolinite.
RA	Quartz (SiO_2), Anhydrite ($CaSO_4$), Feldspar, Calcite ($CaCO_3$), Potassium chlorite (KCl) and Halite (NaCl).

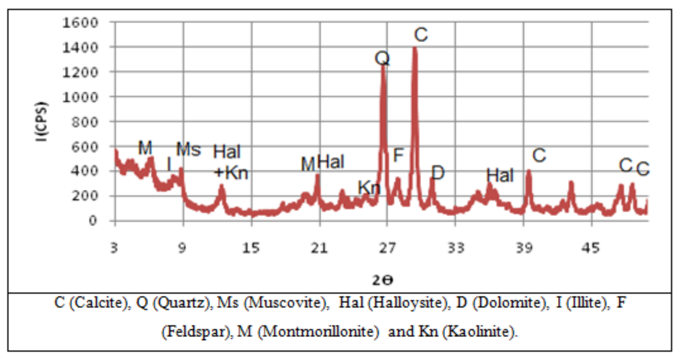


Fig. 10. XRD of the natural soil.

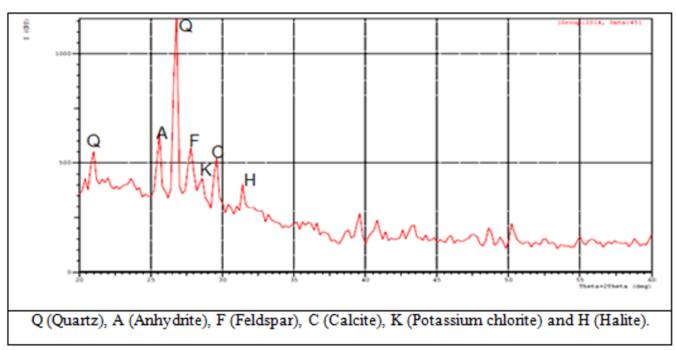
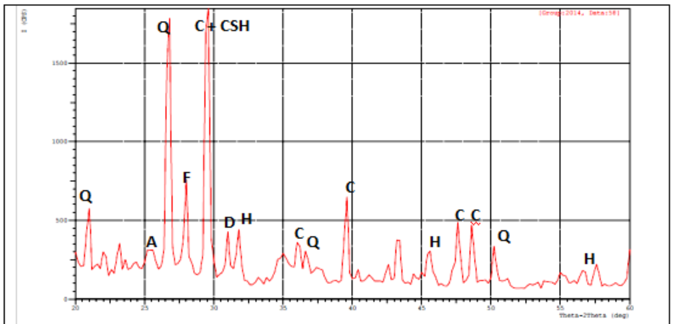


Fig. 11. XRD of reeds ash (RA).



C (Calcite), Q (Quartz), A (Anhydrite), F (Feldspar), H (Halite), CSH (Calcium silicate hydrate) and D (Dolomite).

Fig. 12. Treated soil with 12% RA.

VI. CONCLUSION

In the light of experimental tests, the following conclusions can be drawn:

1. There is a decrease in specific gravity of soil with increasing reed ash (RA) content. MDD is decreased too with increasing RA content resulting in large particles with larger voids and hence less density due to the relatively lower specific gravity of RA compared to soils. While OMC is increased as RA content increases up to 12%.
2. For soft soil-RA mix, there is an increase in liquid and plastic limits, a reduction in the plasticity index of treated soil.
3. It is noticed that UCS and CBR increase by about 86 and 227% respectively with increasing the addition of RA which is due to pozzolanic reactions.
4. It can be noted that RA addition can improve the compressibility of soft clay soils by reducing the compressibility index C_c due to the flocculation and cementitious phenomenal effects by the pozzolanic reactions that forms the secondary minerals.
5. For microstructural analysis of natural soils**,** the SEM-micrographs for 12% RA treated soils show crumbs of floccules with a porous nature and cementitious compounds coating the clay particles.
6. From UCS and CBR tests, it can be concluded that 6 to 9% are the optimum dosage of RA in which it can be added to improve the geotechnical properties such problematic soft soil. Accordingly, the general relationship between q_u and CBR-values with the quality of the subgrade soils used in pavement applications for RA addition consider treated soil as a good subgrade material and it also can be used as highway sub-base material.

REFERENCES

[1] E. W. Brand and R. P. Brenner, *Soft Clay Engineering*, Elsevier Scientific Published Company, Amsterdam, 1981.

[2] *British Standard B.S*: C.P. 8004, "Code of Practice for Foundations," British Standard Institution, London, 1986.

[3] B. B. Broms, "Stabilization of soft clay in Southeast Asia," *Proc. 5th International Geotechnical Seminar*, 2- 4 Dec., 1987.

[4] Z .W. Abbawi, "Proposed techniques for improving soft soil underneath a ballasted track," Ph.D. thesis, Building and Construction Engineering Department University of Technology, Baghdad, Iraq, 2010.

[5] A. Fauzi, W. M. Nazmi, and U. J. Fauzi, "Sub grade stabilization of Kuantan clay by using fly ashes and bottom ash," *Proc. 8th International conference on Geotechnical and Highway Engineering (Geotropika 2010)*, UTM, Sabah, 2010.

[6] *ASTM D 2487*: "Standard practice for classification of soils for engineering purposes (Unified Soil Classification System)," American Society of Testing and Materials, 2000.

[7] *ASTM D 854*: "Standard test methods for specific gravity of soil solids by water Pycnometer, "Annual Book of ASTM Standards, ASTM International, West Conshohocken, PA, United States, 2002.

[8] *ASTM D 4318*: "Standard test methods for liquid limit, plastic limit, and plasticity index of soils," West Conshohocken, PA, United States, 2000.

[9] *ASTM D 1557*: "Standard test methods for laboratory compaction characteristics of soil using modified effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))," Annual Book of ASTM Standards, ASTM International, West Conshohocken, PA, United States, 2000.

[10] *ASTM D 2166*: "Standard test method for unconfined compressive strength of cohesive soil," West Conshohocken, PA, United States, 2000.

[11] *ASTM D 1883*: "Standard test method for CBR (California Bearing Ratio) of laboratory-compacted soils," Annual Book of ASTM Standards, ASTM International, West Conshohocken, PA, United States, 2002.

[12] *ASTM D 2435*:"Standard test method for one-dimensional consolidation properties of soils," Annual Book of ASTM Standards, ASTM International, West Conshohocken, PA, vol. 04.08, 1996, pp. 1–10.